Technical Note

ISSN 1997-1400 Int. J. Pavement Res. Technol. 2(6):275-279

Improved Porous Noise-Reducing Asphalt Mixture Design Method

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Abstract: Traffic noise is becoming an ever-increasing problem for environmental conservation and the health of residents who live near highways. In this paper, porous noise-reducing asphalt mixtures were designed according to a traditional aggregate grading envelope and an improved aggregate grading envelope. The scattering loss index, which was about 13% with the traditional design method, was approximately 6% with the improved method. Noise reduction and better durability can be achieved with the improved asphalt mixture. Furthermore, the cost of construction was only increased by a small amount. A test road section was paved from Ji'nan to Liaocheng freeway according to the improved porous noise-reducing asphalt mixture design method. Every index of the test section was measured, and the noise reduction was surveyed. The results showed that the indices of improved porous noise-reducing asphalt mixture were superior to those of the traditional design method. All the indices satisfied the design requirements.

Key words: *Asphalt content; Asphalt mixture design; Pavement noise; Porous noise-reducing pavement; Scattering loss.*

Introduction

On the basis of domestic and overseas porous noise-reducing asphalt mixture design studies, the void content of this pavement is required to be at least 15%; and in order to prevent clogged pores, the initial void content of the mixture compositions must be 20% or higher. Therefore, the porous asphalt mixture must be designed such that the desired void content is achieved in addition to ensuring adequate strength, temperature stability and durability. Gradation selection and optimal asphalt content determination were performed by experiment.

Traditional Noise-Reducing Asphalt Mixture Design

Optimal Aggregate Gradation Selection

According to the traditional aggregate grading envelope shown in Table 1 [1, 2], three gradations were designed as shown in Fig. 1.

Composite Gradation 1: 51% basalt 10-15; 24% basalt 5-10; 13% basalt 3-5; 8% limestone machine-made sand; 4% filler.

Composite Gradation 2: 53% basalt 10-15; 24% basalt 5-10; 10% basalt 3-5; 8% limestone machine-made sand; 5% filler.

Composite Gradation 3: 55% basalt 10-15; 26% basalt 5-10; 7% basalt 3-5; 8% limestone machine-made sand; 4% filler.

As indicated in Fig. 1, three composite gradations followed the traditional aggregate grading envelope. Thus, the designed gradation had to be determined by experiment. The asphalt content was set to 4.5% according to the oil film method in the experiment. Four Marshall samples were generated for every composite gradation. Every sample was compacted with a Marshall hammer with fifty blows on the top and bottom, respectively. The test results are shown in Table 2. Obviously, the void contents of the three gradations were all beyond 20%. However, the permeability coefficient of Gradation 2 was higher than those of the other two. As shown in Fig. 1, the percentage passing the 2.36*mm* sieve of Gradation 2 was close to the gradation middle value. Generally, the dust-to-binder ratio ($P_{0.075}/P_{be}$) was not suitable if it was less than 1-1.2. Therefore, Gradation 2 was adopted following the industry standard of the People's Republic of China [3].

Optimal Asphalt Content Determination

Because the relationship between the characteristic parameters of the porous asphalt mixture and asphalt content did not have a peak value, the optimal asphalt content was not determined by the Marshall test method [4, 5]. In this study, it was determined by abrasion test. With 4.5% asphalt content, as selected previously, six different asphalt contents (3.5, 4.0, 4.5, 5.0, 5.5, and 6.0% by mass) were used in the experiment. Four Marshall samples were collected for each level of asphalt content according to Gradation 2. Every sample was compacted with fifty blows of a Marshall hammer on the top and bottom, respectively. The test results are shown in Table 3. It was obvious that the void content generally decreased as asphalt content increased. When the asphalt content reached between 5.5 and 6.0%, the void content was less than 20%. Therefore, in order to obtain the desired void content, asphalt content must be under control [6].

According to the data collected previously, optimal asphalt content was not determined. Thus, Marshall samples were used in a scattering test; scattering loss was required to be less than 20%. In addition, drainage loss was verified by the drainage test. The test results are shown in Figs. 2 and 3.

As shown in Fig. 2, as asphalt content increased, the scattering loss generally decreased; when asphalt content exceeded 4.5%, the loss gradually increased. In general, scattering losses were all less than 20%. Therefore, in order to determine optimal asphalt content, the drainage test must be performed for verification.

From the relationship between asphalt content and scattering loss, it could be concluded that scattering loss achieved the lowest value

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Note: Submitted August 3, 2008; Revised March 9, 2009; Accepted April 24, 2009.

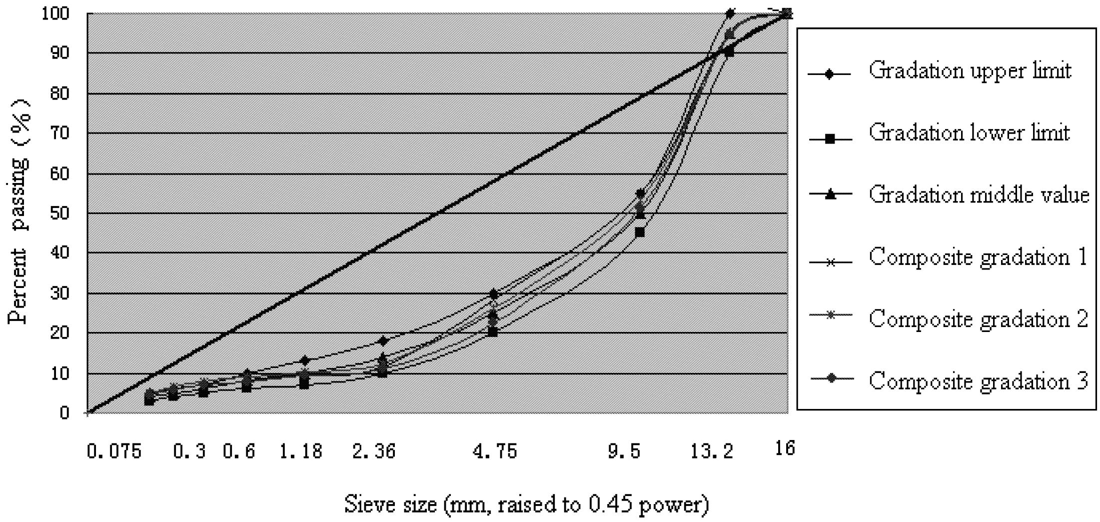

Fig. 1. Three Preliminary Aggregate Gradation Curves.

Table 1. Traditional Aggregate Grading Envelope.

Sieve Size (*mm*)	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Gradation Upper Limit (%)	100	100	55	30	18	13	10	7	6	5
Gradation Lower Limit (%)	100	90	45	20	10	7	6	5	4	3

Table 2. Three Preliminary Gradation Test Results.

Composite Gradation	Bulk Specific Gravity (t/m^3)	Maximum Theoretical Specific Gravity(t/m^3)	Void Content (%)	Permeability Coefficient (*cm/s*)
Gradation 1	1.992	2.564	22.335	0.457
Gradation 2	1.991	2.563	22.302	0.633
Gradation 3	1.986	2.562	22.485	0.614

Table 3. The Specific Gravity and Void Content of the Samples.

Asphalt Content (%)	Bulk Specific Gravity (t/m^3)	Maximum Theoretical Specific Gravity(t/m^3)	Void Content (%)
3.5	1.998	2.604	23.279
4.0	1.991	2.583	22.913
4.5	2.033	2.563	20.658
5.0	2.024	2.543	20.399
5.5	2.027	2.523	19.672
6.0	2.032	2.504	18.831

when the asphalt content was 4.5%; further, when the drainage loss was less than 0.1%, as shown in Fig. 3, the void content was greater than 20%. Thus, optimal asphalt content was determined to be 4.5%.

Other Technical Indices Verification

In this study, Marshall specimens were prepared in the laboratory for experimental verification of other technical indices, such as Marshall stability and flow value (75-blow Marshall compaction), residual Marshall stability, dynamic stability, split strength ratio, and the permeability coefficient. From the experimental results, it was concluded that specimens with 4.5% asphalt by mass were able to meet the requirement. Therefore, optimal asphalt content was set to be 4.5% by mass. In general, under the traditional aggregate grading envelope condition, asphalt content was approximately 4.5%, and scattering loss was 13%.

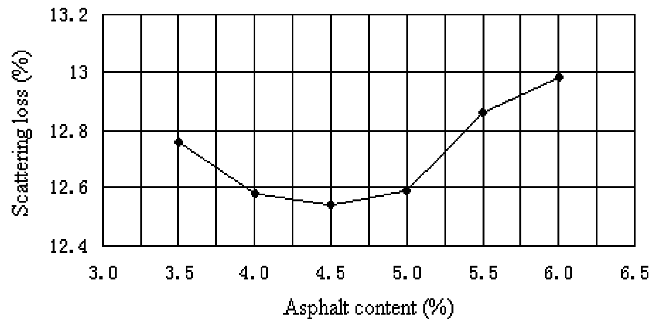

Fig. 2. Relationship between Asphalt Content and Scattering Loss.

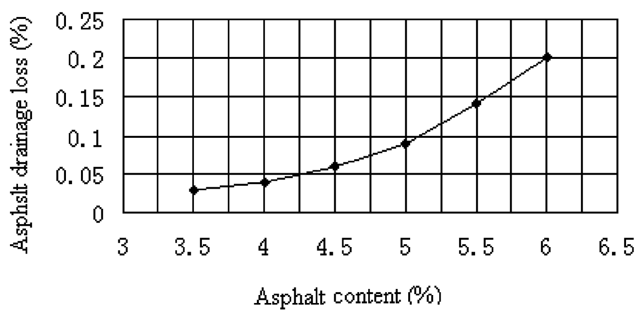

Fig. 3. Relationship between Asphalt Content and Drainage Loss.

Table 4. Improved Aggregate Grading Envelope.

Sieve Size (*mm*)	16	13.2	9.5	4.75	2.36	0.075
Gradation Upper Limit (%)	100	100	75	24	10	4
Gradation Lower Limit (%)	100	82	54	10	4	2

Table 5. Marshall Sample Parameters.

Composite Gradation	Dry ramming Specific Gravity (t/m^3)	Maximum Theoretical Specific Gravity (t/m^3)	Void Content (%)	VCA_{MIX} (%)	VCA_{DRC} (%)	Permeability Coefficient (*cm*/s)	Drainage Loss (%)
Gradation 1	1.919	2.558	20.8	31.8	47.9	128.3	0.075
Gradation 2	1.910	2.560	21.4	32.2	46.0	160.7	0.075
Gradation 3	1.900	2.562	21.3	32.5	43.5	156.6	0.080

Table 6. Marshall Specimen Test Results.

Asphalt Content (%)	Bulk Specific Gravity (t/m^3)	Maximum Theoretical Specific Gravity (t/m^3)	Void Content (%)	Drainage Loss (%)	Scattering Loss (%)	Permeability Coefficient (*m*/d)
6.0	2.071	2.560	19.1	0.105	6.1	86.9
6.3	2.089	2.548	18.1	0.120	3.7	69.2
6.6	2.051	2.536	19.1	0.125	4.5	98.4

Table 7. Rutting and Freeze-Thaw Split Test Results.

Indices	Freeze-Thaw Split Strength Ratio (TSR) (%)	Dynamic Stability (times/*mm*)
Results	104	7,941

Table 8. Four Sample Extract Test Results.

Samples	Asphalt Mixtures(*g*)	Dry Asphalt Mixtures (*g*)	Asphalt Content (%)
Sample 1	1,095.01	1,029.09	6.02
Sample 2	1,058.32	995.56	5.93
Sample 3	1,481.94	1,393.32	5.98
Sample 4	1,200.58	1,129.03	5.96

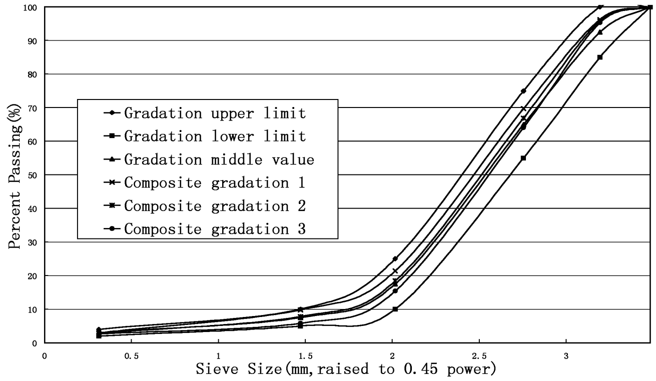

Fig. 4. Three Aggregate Gradation Curves.

Improved Noise-Reducing Asphalt Mixture Design

In this part, the noise-reducing asphalt mixture design was based on an improved aggregate grading envelope (Table 4) proposed by the National Center for Asphalt Technology (NCAT) in the No.99-3 report [7].

Optimal Aggregate Gradation Selection

In terms of the improved aggregate grading envelope shown in Table 4, three gradations (fine, medium, and coarse) were designed as shown in Fig. 4.

Composite Gradation 1: 39% basalt 10-15; 47% basalt 5-10; 8% basalt 3-5; 3% limestone machine-made sand; 3% filler.

Composite Gradation 2: 43% basalt 10-15; 47% basalt 5-10; 4% basalt 3-5; 3% limestone machine-made sand; 3% filler.

Composite Gradation 3: 47% basalt 10-15; 47% basalt 5-10; 0% basalt 3-5; 3% limestone machine-made sand; 3% filler.

In order to select the optimal gradation, four Marshall samples were generated for every composite gradation. In this experiment, asphalt content was set to be 6.0% by mass, while fiber was set to 0.4%. Every sample was compacted with fifty Marshall hammer blows on the top and bottom, respectively. The test results are shown in Table 5. According to the test results, composite Gradation 2 was selected to be the optimal aggregate gradation.

Optimal Asphalt Content Determination

Composite Gradation 2 was optimal aggregate gradation. Marshall specimens were created with 0.4% of fiber, and 6.0, 6.3, and 6.6% Styrene Butadiene Styrene (SBS)-modified asphalt, respectively. The tests were conducted for every sample, and each was compacted with fifty Marshall hammer blows on the top and bottom, respectively. The experimental results are shown in Table 6.

With 18% void content and 6.2% asphalt content, the concerned indices(such as drainage loss, scattering loss, and permeability coefficient) met the requirement, and the specific gravity reached the maximum value.

Mixture Proportion Verification

According to the design results from above, the rutting and freeze-thaw split test data are given in Table 7. It can be seen that the optimal asphalt content was greater than 6% for the improved mixture design method when the void content was limited to 20%. The main control index, scattering loss, was about 6% using the improved method. Other indices were also superior to those obtained from the traditional design method.

Results and Analysis

The noise-reducing asphalt mixture was designed according to the new-improved method, and the design results were used to pave a test road section from the city of Ji'nan to Liaocheng freeway, with a section depth of 4*cm* depth and length of 1,500*m*. The noise reduction was surveyed.

Table 9. Extract-Gradation Test Results.

Sieve Size (*mm*)	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Design Gradation	100.00	93.7	66.34	18.52	7.86	6.45	5.06	4.38	3.84	3.03
Sample 1	100.00	94.78	65.75	17.55	5.40	5.00	4.70	4.29	3.79	2.99
Sample 2	100.00	95.88	66.37	18.79	8.51	7.11	5.83	5.42	5.11	4.57
Sample 3	100.00	94.74	60.71	17.62	6.37	5.11	3.88	3.52	3.29	2.90
Sample 4	100.00	95.09	66.63	18.13	6.31	5.40	4.90	4.20	4.00	3.40
Average Value	100.00	95.12	64.87	18.02	6.65	5.66	4.83	4.36	4.05	3.47

Table 10. Drainage Test Results.

Samples	Drainage Loss (%)
Sample 1	0.11
Sample 2	0.07
Average Value	0.09

Table 11. Scattering Test Results.

Samples	Scattering Loss (%)
Sample 1	9.13
Sample 2	6.78
Sample 3	7.63
Sample 4	9.23
Average Value	8.19

Table 12. Field Void Content Survey Test Results.

Cores	Maximum Theoretical Specific Gravity(t/m^3)	Bulk Specific Gravity (t/m^3)	Field Void Content (%)
Core 1	2.546	2.111	17.1
Core 2		2.092	17.8
Core 3		2.031	20.2
Core 4		2.029	20.3
Core 5		2.052	19.4
Core 6		2.049	19.5

Table 13. Traffic Noise Comparison of Ordinary Pavement with Noise-Reducing Pavement dB(A).

Measure Location	LAeq	L10	L50	L90	SD
Ordinary Pavement	77.6	78.4	58.5	42.5	13.1
Noise-Reducing Pavement	73.4	74.0	52.9	39.4	13.0
Noise Reduction Value	4.2	4.4	5.6	—	—

Table 14. Vehicle Flow Noise Statistics.

	Oversize Vehicle	Medium Vehicle	Compact Car	Sum	Vehicle Flow/Hour
Overtaking Lane	7	9	30	46	138
Driveway	16	8	11	35	105
Sum	23	17	41	81	243

Experimental Results of Field Test Section

The designed asphalt content was 6.0%; the samples were obtained from the field test section.

According to the surveyed results shown in Tables 8-12, it can be seen that the indices of the improved porous noise-reducing asphalt mixture were superior to those of the traditional design method. Every index of the field-paved test section satisfied the requirement.

Test Road Section Noise Survey Results

The surveying main instrument was a HS6288D sound level meter. The measured data were shown in Tables 13 and 14. From the Tables 13 and 14, it can be seen that the value of the noise reduction was 4.2dB(A) when the vehicle flow per hour was 243 for the noise-reduction pavement. Thus, the design objective was achieved.

Conclusions

The following conclusions have been drawn:

1. The main factors affecting porous asphalt pavement noise reduction were void content and pavement depth. When the pavement durability, noise reduction, cost, and other technical and economic indices were comprehensively considered, the rational pavement design with 20% of void content and 40*mm* of the depth was decided.
2. The asphalt content for the new noise-reducing asphalt mixture, which was about 6%, was larger than that for the traditional mixture, which was about 4.5%. The pavement durability was improved.
3. The indices for the new improved design method, especially the main control index, scattering loss, were superior to those for the traditional method. The scattering losses were about 13 and 6% for the traditional and new designs, respectively. Based on the melioration of the noise-reducing pavement anti-relaxation, road durability was improved.
4. When the vehicle flow was low (243 vehicles per hour), equivalent continue A and statistical sound level L50 of traffic noise were reduced by 4.2 and 5.6dB, respectively.

Acknowledgments

The authors wish to express their gratitude to Doctor Aishe Zhang for his assistance in the process of writing this paper.

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